FFADA
Computer Design of Final Focus Systems for Linear Colliders

Olivier NAPOLY, Bruce DUNHAM
CEA, DSM/DAPNIA/Service d'Etudes des Accélérateurs
CE-Saclay, F-91191 Gif-sur-Yvette CEDEX, France

Abstract

FFADA, for Final Focus Automatic Design and Analysis, is a program which allows the user to automatically design a generic final focus system corresponding to a set of a few basic beam and machine parameters for linear colliders. It also derives the main properties of the designed system in terms of momentum acceptance, tracking, collimation requirements and Oide effect. Finally, the program analyzes the effect of magnet misalignment and field errors on the beam parameters and luminosity at the interaction point.

1 INTRODUCTION

Final focus systems (FFS) must reduce the colliding beam to nanometer spot sizes at the interaction point (IP) of future linear colliders. With the transverse emittances foreseen, the corresponding β^* are in the range of 0.1–1mm. The main difficulty is then to correct the chromatic aberrations which dominate the linear optics as soon as the energy spread is larger than β^*/l^*, where l^* is the distance separating the IP from the last focusing quadrupole. A generic system, adapted from the SLC final focus optics [1] has been derived [2, 3] which is free from 2nd and 3rd order aberrations. This solution is highly symmetric, provides several image points of the IP to monitor the beam, and contains the minimal number of four sextupoles (two non-interleaved pairs) for the chromatic correction. It is well adapted to designs where the beam energy spread is below 1% and, with additional sextupoles [4, 5], it can provide a larger energy acceptance.

The generic system is a telescopic transfer line which includes: a matching telescopic transformer (MT) with π–phase advance, achieving the first demagnification of the beam with two quadrupole doublets; a chromatic correction section (CCS); that is, a +1–transformer with 4π–phase advance including two sextupole pairs to cancel the second order chromatic aberrations generated mainly by the last focusing doublet; a final telescopic transformer (FT) achieving the final demagnification of the beam to the desired spot size at the IP, with π–phase advance again and two quadrupole doublets.

In this paper we describe the computer program FFADA which automatizes the operations needed to design and analyze such a generic final focus system. In this way, a FFS can be rapidly optimized for a set of basic beam and machine parameters, and adapted to later changes of these parameters. After generating the telescopic transfer line matched to second order, FFADA analyzes the following properties:

1) the energy acceptance of the system, both analytically and by tracking;
2) the beta-functions and beam envelopes in the last doublet down to the IP;
3) the effect of the synchrotron radiation in the last doublet on the beam spot size [6] and the beam collimation requirements;
4) the sensitivity of the luminosity to beam transverse offset and dispersion at the IP;
5) the tolerances to misalignment and field errors of the magnets of the system.

FFADA runs under UNIX SystemV with FORTRAN and the optics code MAD [7] available. Its structure is modular so that new functions can be easily included. The results are presented in a few output files associated with each modules, and in a series of output files for graphics presentation. An extended presentation of the program FFADA can be found in [8].

2 INPUT PARAMETERS

For the sake of the presentation, we consider an hypothetical design for a "future linear collider", abbreviated to **flc**. The final focus sytem derived by FFADA and its properties are essentially determined by two input data files. The final focus optics depends on the optics and hardware parameters defined in the file **flc.ffs**, while the properties of the system, such as the bandwidth, the beam envelopes or the tolerances, are determined by the beam parameters given in the **flc.beam**.

FLC BEAM			
Energy	[GeV]	:	250.
Horizontal RMS at the IP	[nm]	:	100.
Vertical RMS at the IP	[nm]	:	10.
Horizontal normalized emittance	[m]	:	1.0e-6
Vertical normalized emittance	[m]	:	1.0e-8
Longitudinal RMS	[mm]	:	0.1
Relative energy RMS		:	1.e-3
Energy profile case	[-1=linear, 0=zero]	:	1
Bunch population		:	1.0e+10
Repetition rate	[Hz]	:	1.0e+2

Table 1 : Beam parameter definitions at the IP

2.1 Beam parameters

The desired beam parameters at the IP are defined in `flc.beam` (see Table 1). The transverse and longitudinal distributions are assumed Gaussian. The energy distribution is the superposition of an incoherent Gaussian distribution and a coherent energy profile $\delta(z)$ along the bunch which describes the combined effect of the RF accelerating phase and longitudinal wakefield. If not zero, the energy profile $\delta(z)$ can be selected among several options including linear or user defined profiles.

Input parameters for FFS

Total length of the FFS	[m] :	600.
Total horizontal demagnification	:	50.
Total vertical demagnification	:	100.
Parameters of Final Telescope		
Horizontal FT demagnification	XM = -R22 :	10.
Vertical FT demagnification	YM = -R44 :	20.
Length of last drift	[m] :	3.0
Length of last but one drift	[m] :	0.35
Polarity of last quadrupole	:	D
Length of last quadrupole	[m] :	1.1
Pole-tip field of last doublet quads	[T] :	6.
Aperture diameter of last doublet quads	[mm] :	48.
Length of first drift	[m] :	1.
Length of first doublet quads	[m] :	0.3
Parameters of Matching Telescope		
Polarity of last quadrupole	:	D
Maximum pole-tip field	[T] :	1.4
Aperture diameter of last quad	[mm] :	4.
Length of first drift	[m] :	0.5
Parameters of Microvertex Detector		
Aperture diameter	[mm] :	30.

Table 2 : Optics and hardware parameters of the FFS

2.2 Optics and hardware parameters

The optics, layout and hardware parameters of the final focus sytem which can be freely set are defined in `flc.ffs` (see Table 2). However, some parameters will differ in the final focus system derived by FFADA, namely: the total length of the FFS and the length of the first drift of the 2 telescopes which are the values for the thin lens solution first derived by FFADA, and are modified in the process of matching it to a thick lens one; and, the length of the last quadrupole of the final telescope which is used as a starting value for the optimization of the final telescope [2]. This length l_Q can be initially set from the condition $1/l_Q \simeq K_1(Q)l^*$ that the focal length of the last quadrupole is equal to the length of the last drift l^*. If the starting value is too far from l_Q, a thin lens solution might not be reached for the final telescope.

The aperture of the vertex detector is only used to evaluate the beam collimation requirements from the constraint that the beam-generated synchrotron radiation must not impact on it.

3 DESCRIPTION OF THE PROGRAM

FFADA is composed of several modules which are executed sequentially. Each one is dedicated to a different function and generates output and graphics files displaying the main results. Some modules needs extra auxiliary input parameters. We now describe these modules in the order in which they are executed. A detailed description of the output and graphics files is given in [8].

3.1 TELE4: analytic derivation of a thin lens solution

This module generates an analytic solution for the 2 telescopes where the last quadrupole of each telescope is a thick lens as fixed by `flc.ffs`, and the first 3 are thin lenses. This solution is obtained by solving, for the given demagnifications, the 6 dimensional system obtained by expressing the 6 independent elements of the horizontal and vertical transfer matrices as functions of the strength of the 3 thin lenses and the length of the 3 following drifts, using the solution given in [9]. Once the total length of the telescopes is known, the CCS optics is scaled to match the total length of the FFS given in `flc.ffs`.

Starting from an analytic solution for 2-doublet telescopes where the last quadrupole is already a thick lens, allows the program to automatically find a solution with 4 thick lenses.

3.2 MAD: 2nd order matching of the FFS and bandwidth calculation

This module calls the MAD program [7] in order to perform the following operations:

1. read the thin lens telescope optics generated above and the MAD input file `ccs.mad` describing the optics of the CCS;
2. match the optics of the line (MT , CCS , FT) to first and second order, with thick elements;
3. plot layout, beta-functions and dispersion;
4. plot the energy dependent beta-functions at the IP;
5. store the matched FFS optics in a MAD file.

The MAD file `ccs.mad` describing the generic CCS optics is provided with the program. With some restrictions as to the coherence of the program, it can be modified and even replaced by the user to describe another correction system.

3.3 TRACK: tracking simulations

This module calls MAD to perform tracking simulations of the FFS. A first simulation is made for 2 bunches of typically 10,000 particles distributed as defined in `flc.beam`. The beam spot sizes and the luminosity from the 2 colliding bunches are calculated from the resulting distributions. A second set of simulations is made to analyze the energy acceptance of the system. The spot sizes and luminosity are calculated for beams with Gaussian energy spread varying typically from 0 and 1%. In all cases the beam-beam forces are neglected.

This tracking module can also be activated with the program DIMAD [10]. However, this requires using a modified version of the DIMAD code in which beam energy profiles $\delta(z)$ can be generated and tracked. With the latest MAD versions (8.14 or later) as well as with DIMAD, the stochastic effect of synchrotron radiation in the magnets is taken into account.

3.4 *DBLT: beam envelopes in the last doublet, collimation and Oide effect*

This module calculates and plots various quantities relevant to the last doublet optics and to the interaction region, namely:

1) the Twiss β and α functions and the beam envelopes from the last doublet down to the IP;
2) the beam collimation requirement arising from clearing the synchrotron radiation generated by the beam in the last doublet, through a vertex detector located at the IP, and through the opposing doublet with hyperbolic or circular aperture. The requirement which minimizes the population of collimated particles, for a uniform distribution of halo, is given and used in the graphics output;
3) the Oide limit [6] for the horizontal and vertical spot sizes at the IP. The calculation is done both analytically and by tracking with MAD (or DIMAD).

3.5 *DIFFLUM: luminosity loss versus beam offset and dispersion at the IP*

For head-on collision, the luminosity is at a maximum with respect to the beam offset, dispersion and coupling at the IP. This module calculates the nominal luminosity expected for head-on collisions and the second order derivatives [11] of the luminosity with respect to the transverse position and angular offsets and dispersions of the *two beams* at the IP. In the calculations, the"hour-glass" effect is taken into account while the pinch effect is not.

3.6 *ERROR: magnet misalignment and field errors, tolerances*

After summarizing the number and types of the magnets included in the system, this module performs a detailed analysis of the effect of small 3d-displacements, 3d-rotations and field errors of the quadrupole and sextupole magnets. These effects are translated to the beam centroid and beam matrix at the IP and analyzed in terms of relative beam offset, dispersion, spot size growth, waist shift and xy-coupling at the IP.

Then, restricting to the 2d-transverse misalignments, the loss of luminosity resulting from uncorrelated random motion of all magnets of the two FFS (except the last doublet) on the one hand, and fixed displacement of the quadrupoles of the two opposing doublets on the other hand, is calculated using the 2nd order derivatives derived in DIFFLUM. This analysis is repeated with the assumption of a perfect steering correction of the beams at the IP. In the case of no steering, i.e. for uncorrected vibrations, the luminosity reduction arises mainly from the relative beam position offset. In the case where the offset is corrected, the reduction arises from the remaining dispersion, including that introduced by the two opposing steering kickers which are located at the first doublet of the last telescope.

4 FUTURE DEVELOPMENTS

We have presented the first version of the program FFADA. This computer program has been written to facilitate the design, optimization and evolution of final focus systems for linear colliders. It also performs the analysis of the most important properties of the system, such as bandwidth, collimation or tolerances, and then launches tracking simulations of the line. The needed input parameters are meant to be as few and basic as possible. The further developments envisaged are as follows:

1) analyze the effect of misalignment and field errors of the dipole magnets;
2) implement the dependence of the luminosity on the 4×4 transverse phase-space submatrix of the FFS transfer matrix (e.g. include waist-shifts and xy-coupling);
3) derive tolerances on the second and higher order field errors (sextupole and higher multipoles);
4) extend the program to non-zero crossing angle;
5) interface the program with standard or widely distributed graphics software (GKS, HIGZ, TopDraw).

5 REFERENCES

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